NASA Hurricane and Severe Storm Sentinel (HS3) Observations for Testing Environmental Control of Hurricane Formation and Intensification

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Award Number: N0001412WX21567

LONG-TERM GOAL

The long-term goal is to utilize the NASA Global Hawk unmanned aircraft observations to advance understanding of Atlantic tropical cyclone formation and intensification.

OBJECTIVES

Advancement in the understanding and prediction of tropical cyclone formation and intensification requires observational studies of the combined effects of vertical wind shear, evaporational cooling in saturated convective-scale downdrafts, and the physical processes occurring along two air streams: (i) an equatorial source of warm, moist air with maximum winds in the lower troposphere; and (ii) a subtropical source of cool, dry air with maximum winds in the mid-troposphere. Although a mesoscale convective circulation is considered to be an essential element, it is hypothesized that the environmental properties in the two air streams control the timing and location of the formation of the tropical cyclone. Global Hawk observations are required along both air streams flowing into the region of the pre-tropical cyclone seedling. The objectives are to document the environmental conditions and the physical processes that lead to the spinup of the mesoscale vortex that becomes the inner core of the tropical cyclone to the southeast of the synoptic-scale circulation center, but inhibit formation to the northwest. The two long-duration, high altitude NASA Global Hawks devoted to Environmental and Over-Storm missions with various remote sensing instruments are uniquely suited for these required observational studies.

Mission planning for a field experiment observing a relatively rare event such as a mature tropical cyclone can be rather difficult when an expensive and heavily-instrumented platform is only available for a limited amount of time and with a limited number of flight hours. Questions may include: Will a

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 SEP 2013		**00-00-2013 to 00-00-2013**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
NASA Hurricane and Severe Storm Sentinel (HS3) Observations for Testing Environmental Control of Hurricane Formation and Intensification	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Postgraduate School,Department of Meteorology,Monterey,CA,93943**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**5**	

target storm be available within the range of the aircraft in the first (of five) week? If not in the first week, in the second week? If a rather marginal storm is available early in the field experiment, should that storm be observed or wait for better storms later? Will there be a 2+ week gap of no storms during the field experiment due to unfavorable phase of the Madden-Julian Oscillation?

Our research team had provided extended-range forecast support for the Impact of Typhoons on the Ocean in the Pacific (ITOP) during August-October 2010 utilizing the 51-member European Center for Medium-range Weather Forecasts (ECMWF) 32-day ensemble predictions. These ensemble predictions made twice a week were able to predict the formation and subsequent tracks of typhoons and many tropical storms and depressions 3-4 weeks in advance. In addition, the ECMWF ensemble was able to predict a three-week period of no tropical cyclones in the western North Pacific during the climatologically active time in the typhoon season. The second objective was to provide such extended-range tropical cyclone forecasts of formation and tracks in support of HS3.

APPROACH

We participated in the planning meeting to describe our hypotheses, and then participated in the 2012 HS3 field experiment to obtain NASA Global Hawk (GH) observations to test two hypotheses related to environmental properties favorable or unfavorable for tropical cyclone formation. Observations were sought along a warm and moist air stream flowing into a convective burst region to the southeast of the pre-tropical seedling circulation center that leads to the spin-up of a mesoscale vortex that then becomes the inner core of the tropical cyclone. Observations were also sought along a cool and dry air stream on the northern side to verify a physically-based hypothesis for why such a lower-level mesoscale vortex does not form to the northwest of the circulation center.

Because we were proposing to provide extended-range forecast support for HS3, the ECMWF provided in real-time (about synoptic time plus 16 h) the tracks of all tropical cyclone-like vortices in the Atlantic predicted by the 51 members over the 32-day forecast interval. We combined those vortices with similar formation locations and similar tracks into "ensemble storms." A special aspect of our approach is to not assume equal likelihood to all ensemble vortices; rather, we discard all tracks less than 72 h and give greater (smaller) weight to the 12-h motion vectors of vortices that are close (far from) the position at the end of the prior 12-h period. Although we had no prior experience with extended-range forecasts of Atlantic tropical storms, we also subjectively discarded any ensemble storms that were likely to be false alarms based on our previous experience in the western North Pacific (Tsai et al. 2013).

Beginning in mid-August 2012 as HS3 was getting organized, we provided the mission planning team Week 1, Week 2, Week 3, and Week 4 forecasts of tropical cyclones twice a week. We also utilized the daily 0000 UTC ECMWF 15-day ensemble forecasts to provide intermediate Atlantic tropical cyclone formation and track guidance between the Monday and Thursday ECMWF 32-day ensemble predictions. Although these 15-day forecasts are delayed relative to the 5-day deterministic NCEP GFS and ECMWF forecasts used by the HS3 forecast team, the longer-tracks from the ECMWF 15-day ensemble occasionally provided useful guidance for mission planning. When AV1 was delayed, and the possibility was raised that it might be deployed from Dryden into eastern North Pacific tropical cyclones, we also began making Week 1 through Week 4 forecasts for that basin in late September.

RESULTS

We were also provided access to the full-resolution ECMWF deterministic model forecast fields each 12 h beginning in late August 2012. Two trajectory programs were developed for hypothesis testing. Unfortunately, only one tropical cyclone formation (Nadine) was observed by AV6. Even though an excellent mission flight plan was developed, the crucial dropwindsondes necessary for validating the ECMWF deterministic model winds and moisture failed due to a mechanical problem. Thus only the SHIS observations are available to examine the moisture fields along the GH track.

During the past year, Professor Pat Harr has been working with NASA and other government agency researchers to explore opportunities for Global Hawk deployment to the western North Pacific following HS3. The experiences gained from the 2012 HS3 field experiment have been very helpful in these discussions. Professor Harr will thus continue these collaborations in the coming year.

An evaluation of the performance of the ECMWF 32-day ensemble in predicting the formations and tracks of the Atlantic tropical storms and hurricanes from May 31 to December 17, 2012 has been presented at the HS3 workshop, Interdepartmental Hurricane Conference (IHC), and ONR Seasonal Prediction Workshop (Elsberry et al. 2013a, b, c) and submitted for publication to *Weather and Forecasting* (Elsberry et al. 2013d). For the HS3 workshop and IHC, the primary focus was the characteristics of the successful forecasts, especially during the HS3 experiment when the formations and subsequent tracks were generally well forecast. However, both the early season and late season storms (including Superstorm Sandy) had more limited success with only the early portions of the tracks being forecast. The most surprising result from the 2012 Atlantic season was that the twice weekly ECMWF 32-day ensemble predictions did not forecast during any of the four weeks three baroclinically-forced storms [Hurricanes Chris (AL03) and Michael (AL13) and Tropical Storm Tony (AL19)] and Tropical Storm Patty, which was a short-lived storm that formed at 25ºN, 74ºW from mesoscale processes. Thus, the overall extended range forecastability of Atlantic tropical cyclones during the 2012 season was considerably less than we have documented in the western North Pacific (Tsai et al. 2013).

The implications of the limited predictability on the extended-range was the topic of the invited lecture at the ONR Seasonal Prediction Workshop (Elsberry et al. 2013c). Using the same procedures developed for the extended-range forecasts with the ECMWF seasonal forecasts from 1 May, 1 June, and 1 July 2012, useful information on the African Easterly Wave (AEW) type of storms that have westward tracks that may threaten the United States. However, the ECMWF seasonal forecasts for the 2012 Atlantic season essentially had no skill for subtropical formations with northward tracks or the late season tracks that started at low latitudes and moved northward due to strong interaction with the midlatitudes. It is important that these are generally the same storms that the ECMWF extended-range predictions failed to forecast even one week in advance. We will use this in our support of mission planning for the 2013 season. More importantly, this result suggests an important predictability limitation for Atlantic tropical cyclones. One outcome of the HS3 observational and modeling studies may be to improve understanding and prediction of these difficult-to-forecast tropical cyclones.

A manuscript summarizing these evaluations of the ECMWF 32-day ensemble predictions of Atlantic tropical cyclones has been submitted to *Weather and Forecasting* (Elsberry et al. 2013d). Working best-tracks for each of the 19 tropical storms and hurricanes from the National Hurricane Center

(NHC) were the basis for matching the corresponding ensemble storm tracks using the objective verification technique of Tsai et al. (2013). Hurricanes Kirk and Leslie and Tropical Storms (TSs) Joyce and Oscar were successfully forecast in Weeks-1, -2, -3, and -4 and thus are labeled as highly forecastable. Somewhat forecastable storms that are only forecast in three of the four weeks include Hurricanes Ernesto, Isaac, Nadine, and Sandy plus TS Florence. The limited forecastable storms that were successful in only the first two weeks included Hurricanes Gordon and Rafael plus TS Debby. As indicated above, the surprising result was that two hurricanes (Chris and Michael) and three TSs (Helene, Patty, and Tony) were not even forecast in the Week-1 before the starting time in the NHC working best-track for these storms. Another important consideration for the forecasters is the number of "false alarm tracks" that could not be matched with a NHC storm track, and the seasonal and geographic characteristics of these tracks are the subject of further study.

IMPACT/APPLICATIONS

This new understanding of the physical processes and the unique data sets will provide the basis for improved numerical model predictions of tropical cyclone formation (and non-formation) and intensification, and ultimately lead to better forecasts and warnings for the Fleet and DoD bases.

RELATED PROJECTS

We continue to pursue the application of extended-range predictions of tropical cyclone formation and tracks in the western North Pacific that were originally developed in the ONR project (N0001412AF00002) of Harr and Elsberry entitled "Western North Pacific Tropical Cyclone Formation and Structure Change in TCS-08." The continuation of this research is funded by Dr. Dan Eleuterio in the ONR project (N0001413WX20778) entitled "Transition of the 32-day and 15-day forecasts of tropical cyclone events to operations in the western North Pacific and extension to other global basins."

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PUBLICATIONS

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